Cross-Coupling of Alkynylsilanols with Aryl Halides Promoted by Potassium Trimethylsilanolate

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SUPPORTING INFORMATION

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General Experimental

All reactions were performed in oven-dried (140 °C) or flame-dried glassware under an inert atmosphere of dry argon. DME was distilled from Na and benzophenone. Brine refers to a saturated aqueous solution of NaCl. Commercial reagents were purified by distillation or recrystallization prior to use.

Analytical thin-layer chromatography was performed on Merck silica or aluminum oxide, basic gel plates with QF-254 indicator. Visualization was accomplished with UV light and/or $KMnO_4$ solution. Diethyl ether was of reagent grade and used as received; other solvents for chromatography and filtration were technical grade and distilled from the indicated drying agents: hexane and pentane ($CaCl_2$); ethyl acetate (K_2CO_3).

^{1}H NMR spectra and ^{13}C NMR spectra were recorded on 500 MHz, ^{1}H (126 MHz, ^{13}C) spectrometers. Spectra are referenced to residual chloroform (δ 7.26 ppm, ^{1}H; δ 77.0 ppm, ^{13}C) and residual benzene (δ 7.16 ppm, ^{1}H; δ 128.0 ppm, ^{13}C). Chemical shifts are reported in ppm (δ); multiplicities are indicated by s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet) and br (broad). Coupling constants, *J*, are reported in Hertz. All ^{1}H and ^{13}C NMR assignments are corroborated by 2D experiments (HETCOR and COSY). Spectra available on request from denmark@scs.uiuc.edu.

Electron impact mass spectroscopy (EI) was performed at 70 eV and chemical ionization (CI) spectra were obtained using methane as the carrier gas. Data are reported in the form of m/z (intensity relative to base peak = 100). Infrared spectra (IR) peaks are reported in cm^{-1} with indicated relative intensities: s (strong, 67-100%); m (medium, 34-66%); w (weak, 0-33%). Analytical capillary gas chromatography (GC) was performed using a gas chromatograph fitted with a flame ionization detector (H_2 carrier gas, 1 mL/min). GC Method 1: Injections were made onto a Hewlett-Packard HP-5 50-m cross-linked 5%-phenyl methyl silicone gum phase column. The detector temperature was 300 °C. The column oven temperature program is as follows: 125 ºC for 4 minutes, 125 ºC to 250 ºC ramp at 50 ºC/minute, 250 ºC for 6 minutes. Total run time is 12.5 minutes. Retention times (t_R) and integrated ratios were obtained from reporting integrators. Bulb-to-bulb distillations were performed on a Kugelrohr; boiling points (bp) corresponding to uncorrected air-bath temperatures (ABT).

Response Factors

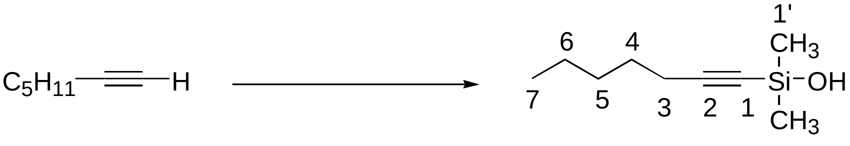
Response factors (R_f) for quantitative GC analysis for GC Method 1 were obtained by the equation below:

Eq1: Response factor for A = (area A * mmol biphenyl)/ (mmol A * area biphenyl)

mmol biphenyl	Area biphenyl	mmol **3a**	Area **3a**	Response factor
0.0492	27437	0.0395	11542	0.524
0.0492	28707	0.0395	12971	0.563
0.0492	17569	0.0395	8831	0.626
0.0182	45830	0.0213	35817	0.668
0.0182	43337	0.0213	40701	0.802
0.0182	25151	0.0213	22347	0.759
0.0253	24665	0.0326	27534	0.866
0.0253	30122	0.0326	28639	0.738
0.0253	35994	0.0326	35740	0.770
			Avg:	0.701

mmol biphenyl	Area biphenyl	mmol 4-iodoanisole	Area 4-iodoanisole	Response factor
0.0389	20906	0.0406	7468	0.342
0.0389	34354	0.0406	13373	0.373
0.0389	22427	0.0406	7699	0.329
0.0175	5928	0.0256	2957	0.341
0.0175	9665	0.0256	5319	0.376
0.0175	14950	0.0256	8801	0.402
0.0454	51497	0.0607	26561	0.463
0.0454	9996	0.0607	5594	0.502
0.0454	49790	0.0607	28626	0.516
			Avg:	0.386

Preparation of Dimethyl-(1-heptynyl)silanol (2)



2

To an oven-dried, 250-mL round-bottom flask equipped with a magnetic stir bar was added 1-heptyne (7.87 mL, 60.0 mmol) and 50 mL of anhydrous ether. The resulting solution was cooled to -75 ^{0}C. To the solution was slowly added *n*-butyllithium (1.55 M in hexane, 38.7 mL, 60.0 mmol, 1.0 equiv) and the solution stirred for 90 min at the same temperature. Chlorodimethylsilane (20.0 mL, 0.18 mol, 3.0 equiv) was added and the solution was allowed to warm to room temperature over 2 hours. The reaction mixture was quenched with 10 mL of water then was extracted with water (20 mL). The aqueous phase was back-extracted with 2 x 20 mL of ether. The combined organics were washed with brine (20 mL) and then were dried over $MgSO_4$. The volatile solvents were removed in vacuo to provide a yellow oil. The oil was taken up in 5 mL of hexanes and then was purified by silica gel chromatography (60 mm x 30 cm) using hexanes to afford the intermediate silane, (8.70 g, 94%) as an colorless oil.

To a 250-mL, round-bottom flask equipped with a magnetic stir bar was added the intermediate silane (11.40 g, 73.8 mmol), 300 mL of acetonitrile, and water (2.66 mL, 147.6 mmol, 2.0 equiv). To the resulting solution was added $[RuCl_2(p\text{-cymene})]_2$ (900 mg, 1.47 mmol, 0.02 equiv). The solution was stirred at room temperature open to the atmosphere for 10 min. The volatile solvents were then was removed in vacuo to provide a red oil. The oil was taken up in 20 mL of hexanes and then was purified by silica gel chromatography (30 mm x 30 cm) using hexanes/ethyl acetate, 5/1 to produce a colorless oil. Short-path distillation (100 °C, 1.0 mmHg) afforded 10.58 g (84%) of dimethyl(1-heptynyl)silanol as a colorless oil.

Analytical Data for **2**

Data for Dimethyl(1-heptynyl)silanol **(2)**:

bp: 100 ^{0}C (1.0 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

2.22 (t, *J* =7.5, 2 H, $H_2C(3)$), 2.04 (s, 1 H, -OH), 1.52 (pent, *J* = 7.5, 2 H, $H_2C(4)$), 1.30-1.36 (m, 4 H, H_2C(5 and 6)), 0.90 (t, *J* = 7, 3 H, $H_3C(7)$), 0.27 (s, 6 H, $H_3C(1')$)

^{13}C NMR: (126 MHz, $CHCl_3$)

107.87 (C(1)), 83.34 (C(2)), 30.97 (C(5)), 28.06 (C(4)), 22.11 (C(6)), 19.62 (C(3)), 13.90 (C(7)), 1.61 (C(1'))

IR: (neat)

3291 (s), 2960 (s), 2935 (s), 2862 (s), 2176 (s), 1467 (m), 1429 (m), 1253 (s), 1049 (m), 900, (s), 830, (s), 787 (s)

MS: (EI, 70 ev)

155 (M-15, 100), 98 (12), 85 (11), 75 (54), 61 (15)

TLC: R_f 0.07 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

Analysis: $C_{17}H_{18}$ (222.32)

Calcd: C, 63.47; H, 10.65%

Found: C, 63.21; H, 10.85%

General Procedure I: Competition Study of Palladium-Catalyzed Cross-Coupling of Alkynylsilicon Compounds with 4-Iodoanisole

To an oven-dried, 5-mL, round-bottom flask equipped with a magnetic stir bar was added 128.2 mg (1.0 mmol, 2.0 equiv) of potassium trimethylsilanolate under a dry argon atmosphere. To this was added sequentially copper(I) iodide (4.8 mg, 0.025 mmol, 0.05 equiv), biphenyl (49.9 mg), 1 mL of DME, dimethyl(1-heptynyl)silanol (93.7 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv). The progress of the reaction was monitored by GC as follows: an aliquot of the reaction mixture was filtered through a small amount of silica gel with EtOAc and was analyzed by GC method 1.

Table 1, entry 1

Following General Procedure I, potassium trimethylsilanolate (128.2 mg, 1.0 mmol, 2.0 equiv.), biphenyl (50.5 mg), 1 mL DME, 1-heptyne (52.9 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (8608, 90%), **3a**, t_R 9.78 min (947, 2%).

Table 1, entry 2

Following General Procedure I, potassium trimethylsilanolate (128.2 mg, 1.0 mmol, 2.0 equiv.), biphenyl (50.5 mg), 1 mL DME, 1-trimethylsilyl-1-heptyne (92.6 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (4533, 106%), **3a**, t_R 9.78 min (0, 0%).

Table 1, entry 3

Following General Procedure I, potassium trimethylsilanolate (128.2 mg, 1.0 mmol, 2.0 equiv.), biphenyl (48.8 mg), 1 mL DME, dimethyl(1-heptynyl)silanol (93.7 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (1687, 24%), **3a**, t_R 9.78 min (3131, 25%).

Table 1, entry 4

Following General Procedure I, potassium trimethylsilanolate (128.2 mg, 1.0 mmol, 2.0 equiv.), copper(I) iodide (4.8 mg, 0.025 mmol, 0.05 equiv), biphenyl (50.4 mg), 1 mL DME, 1-heptyne (52.9 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (14175, 118%), **3a**, t_R 9.78 min (1051, 14%).

Table 1, entry 5

Following General Procedure I, potassium trimethylsilanolate (128.2 mg, 1.0 mmol, 2.0 equiv.), copper(I) iodide (4.8 mg, 0.025 mmol, 0.05 equiv), biphenyl (47.0 mg), 1 mL DME, 1-trimethylsilyl-1-heptyne (92.6 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (14908, 113%), **3a**, t_R 9.78 min (1519, 16%).

Table 1, entry 6

Following General Procedure I, potassium trimethylsilanolate (128.2 mg, 1.0 mmol, 2.0 equiv.), (I) iodide (4.8 mg, 0.025 mmol, 0.05 equiv), biphenyl (49.9 mg), 1 mL DME, dimethyl(1-heptynyl)silanol (93.7 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (0, 0%), **3a**, t_R 9.78 min (46517, 99%).

Table 1, entry 7

Following General Procedure I, tetrabutylammonium fluoride (315 mg, 1.0 mmol, 2.0 equiv.), biphenyl (49.2 mg), 1 mL DME, 1-heptyne (52.9 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (3105, 82%), **3a**, t_R 9.78 min (1196, 17%).

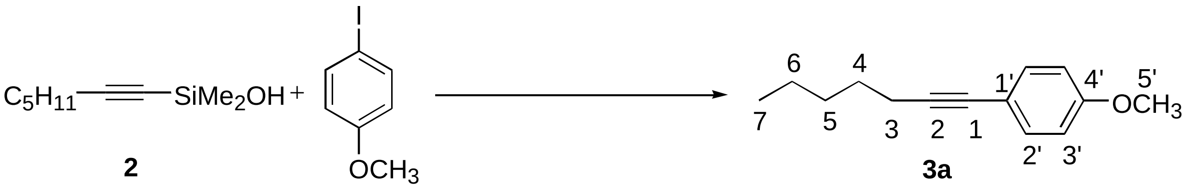
Table 1, entry 8

Following General Procedure I, tetrabutylammonium fluoride (315 mg, 1.0 mmol, 2.0 equiv.), biphenyl (49.6 mg), 1 mL DME, 1-trimethylsilyl-1-heptyne (92.6 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (7212, 83%), **3a**, t_R 9.78 min (3526, 22%).

Table 1, entry 9

Following General Procedure I, tetrabutylammonium fluoride (315 mg, 1.0 mmol, 2.0 equiv.), biphenyl (51.3 mg), 1 mL DME, dimethyl(1-heptynyl)silanol (93.7 mg, 0.55 mmol, 1.1 equiv), 4-iodoanisole (117.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (8.6 mg, 0.0125 mmol, 0.025 equiv) were combined and stirred at rt for 3 h. An aliquot of the mixture was analyzed by GC Method 1: 4-iodoanisole, t_R 7.28 min (4218, 42%), **3a**, t_R 9.78 min (8459, 47%).

General Procedure II: Cross-Coupling of Dimethyl(1-heptynyl)silanol (2) with Aryl Iodides. Preparation of 1-(1-Heptynyl)-4-methoxybenzene (3a)[1]



To an oven-dried, 10-mL, round-bottom flask equipped with a magnetic stir bar was added 256.0 mg (2.0 mmol, 2.0 equiv) of potassium trimethylsilanolate under a dry argon atmosphere. To this was added sequentially copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187.0 mg, 1.1 mmol, 1.1 equiv), 4-iodoanisole (234.0 mg, 1.0 mmol, 1.0 equiv), and $PdCl_2(PPh_3)_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The resulting solution was stirred at room temperature for 3 h under a dry argon atmosphere. The reaction mixture was then filtered through a silica plug (3 g) with 75 mL of anhydrous Et_2O. The volatile solvents were removed in vacuo to afford a yellow oil. The oil was taken up in 3 mL of ether and then was purified by silica gel column chromatography (30 mm x 30 cm) using pentane/ether, 19/1 to give a pale yellow oil. Bulb-to-bulb distillation (ABT 150 ^{0}C, 1.0 mmHg) afforded 191 mg (95%) of **3a** as a colorless oil.

<u>Data for 1-(1-Heptynyl)-4-methoxy-benzene **(3a)**</u>:

<u>bp</u>: 150 ^{0}C (1.0 mmHg, ABT)

^{1}<u>H NMR</u>: (500 MHz, $CHCl_3$)

7.26 (dd, *J* = 2, 7, 2 H, 2 x HC(3’)), 6.75(dd, *J* = 2, 7, 2 H, 2 x HC(2’)), 3.74 (s, 3 H, H_3C(5')), 2.32 (t, *J* =7.5, 2 H, H_2C(3)), 1.52 (pent, *J* = 7.5, 2 H, H_2C(4)), 1.27-1.35 (m, 4 H, H_2C(5 and 6), 0.86 (t, *J* = 7.5, 3 H, H_3C(7))

^{13}C NMR: (126 MHz, $CHCl_3$)

159.21 (C(4’)), 133.10 (C(2’)), 116.49 (C(3’)), 114.03 (C(1’)), 89.07 (C(1)), 80.42 (C(2)), 55.48 (C(5')), 31.36 (C(5)), 28.80 (C(4)), 22.47 (C(6)), 19.60 (C(3)), 14.24 (C(7))

GC: t_R 9.35 min (HP-5, 15 psi, 175 ^{0}C for 7 min, 25 ^{0}C/min to 225 ^{0}C)

Preparation of 1-Phenyl-1-heptyne (3b) (Table 2, entry 2)[2]

2 **3b**

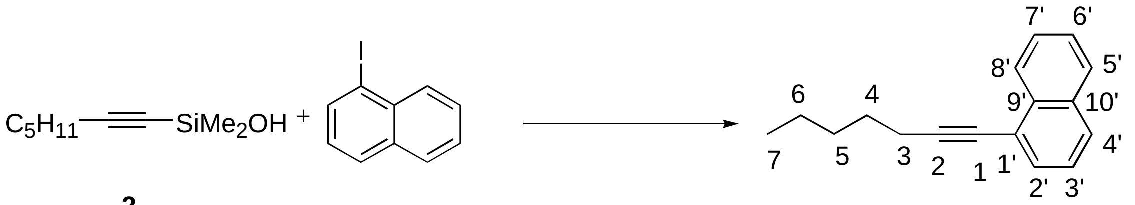
Following General Procedure II, iodobenzene (408 mg, 2.00 mmol) was combined with potassium trimethylsilanolate (512 mg, 4.00 mmol, 2.0 equiv), copper(I) iodide (19 mg, 0.10 mmol, 0.05 equiv), 4 mL of DME, dimethyl(1-heptynyl)silanol (375 mg, 2.2 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (35 mg, 0.05 mmol, 0.025 equiv). The product **3b** was obtained as a colorless oil in 93% yield (320 mg).

Analytical data for 1-Phenyl-1-heptyne **(3b)**

^{1}H NMR: (500 MHz, $CHCl_3$)

7.39-7.40 (m, 2 H), 7.25-7.38(m, 3H), 2.40 (t, *J* =7.0, 2 H, $H_2C(3)$), 1.61 (pent, *J* = 7.5, 2 H, $H_2C(4)$), 1.33-1.42 (m, 4 H, H_2C(5 and 6), 0.92 (t, *J* = 7.0 3 H, $H_3C(7)$)

Preparation of 1-(1-Heptynyl)naphthalene (3c) (Table 2, entry 3)



2 **3c**

Following General Procedure II, 1-iodonaphthalene (508 mg, 2.00 mmol) was combined with potassium trimethylsilanolate (512 mg, 4.00 mmol, 2.0 equiv), copper(I) iodide (19 mg, 0.10 mmol, 0.05 equiv), 4 mL of DME, dimethyl(1-heptynyl)silanol (375 mg, 2.2 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (35 mg, 0.05 mmol, 0.025 equiv). The product **3c** was obtained as a colorless oil in 87% yield (385 mg).

Data for 1-(1-Heptynyl)naphthalene **(3c):**

bp: 160 ^{0}C (0.5 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

8.37 (d, *J* = 8.5, 1 H, HC(8’)), 7.84 (d, *J* = 8.5, 1 H, HC(2’)), 7.79 (d, *J* = 8.5, 1 H, HC(5’)), 7.64 (d, *J* = 7.5, 1 H, HC(4’)), 7.57 (t, *J* = 7.5, 1 H, HC(7’)), 7.51 (t, *J* = 7.5, 1 H, HC(6’)), 7.41 (t, *J* = 7.5, 1 H, HC(3’)), 2.59 (t, *J* =7.0, 2 H, $H_2C(3)$), 1.74 (pent, *J* = 7.5, 2 H, $H_2C(4)$), 1.54 (pent, *J* = 7.5, 2 H, $H_2C(5)$), 1.42 (pent, *J* = 7.5, 2 H, $H_2C(6)$), 0.97 (t, *J* = 7.0, 3 H, $H_3C(7)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

133.5 (C(9’)), 133.2 (C(10’)), 130.0 (C(2’)), 128.2 (C(4’)), 127.8 (C(5’)), 126.4 (C(6’)), 126.3 (C(8’)), 126.2 (C(7’)), 125.2 (C(3’)), 121.8 (C(1’)), 95.6 (C(1)), 78.5 (C(2)), 31.2 (C(5)), 28.6 (C(4)), 22.4 (C(6)), 19.7 (C(3)), 14.0 (C(7))

IR: (neat)

3058 (s), 2931 (s), 2859 (s), 2222 (m), 1928 (w,b), 1586 (s), 1463 (s), 1395 (s), 1328 (m), 1016 (m), 798 (s), 773 (s)

MS: (EI, 70 ev)

222 (M^+, 38), 193 (25), 179 (30), 178 (24), 167 (34), 166 (19), 165 (100), 164 (20), 163 (26), 152 (22), 139 (12)

TLC: R_f 0.52 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

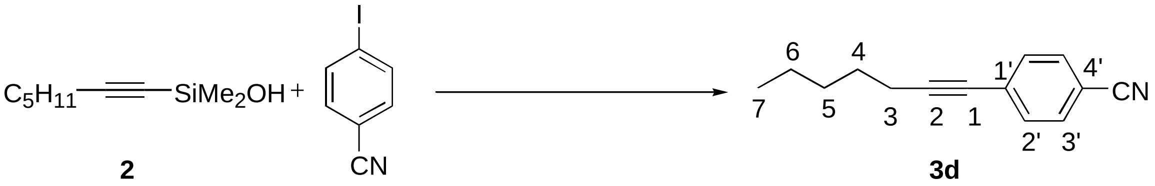
GC: t_R 12.40 min (HP-5, 15 psi, 175 ^{0}C for 7 min, 25 ^{0}C/min to 225 ^{0}C)

Analysis: $C_{17}H_{18}$ (222.32)

Calcd: C, 91.84; H, 8.16%

Found: C, 91.83; H, 8.21%

Preparation of 4-(1-Heptynyl)benzonitrile (3d) (Table 2, entry 4)



Following General Procedure II, 4-iodobenzonitrile (229 mg, 1.00 mmol) was combined with potassium trimethylsilanolate (256 mg, 2.00 mmol, 2.0 equiv), copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187 mg, 1.1 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The product **3d** was obtained as a colorless oil in 83% yield (176 mg).

Data for 4-(1-Heptynyl)benzonitrile **(3d)**:

bp: 150 ^{0}C (0.5 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

7.56 (dd, *J* = 2, 6.5, 2 H, 2 x HC(3')), 6.75 (dd, *J* = 2, 7, 2 H, 2 x HC(2')), 2.42 (t, *J* =7.5, 2 H, $H_2C(3)$), 1.61 (pent, *J* = 7.0, 2 H, $H_2C(4)$), 1.25-1.44 (m, 4 H, H_2C(5 and 6), 0.93 (t, *J* = 7.0, 3 H, $H_3C(7)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

132.3 (C(3')), 132.1 (C(2')), 129.4 (C(1')), 118.8 (CN), 111.0 (C(4')), 95.9 (C(1)), 79.6 (C(2)), 31.3 (C(5)), 28.3 (C(4)), 22.4 (C(6)), 19.7 (C(3)), 14.1 (C(7))

IR: (neat)

2932 (s), 2860 (s), 2227 (s), 1921 (w,b), 1604 (s), 1500 (s), 1466 (s), 1428 (m), 1405 (m), 1330 (m), 1176 (s), 839 (s)

MS: (EI, 70 ev)

197 (M^+, 32), 182, (16), 169 (19), 168 (100), 167 (12), 156 (12), 155 (39), 154 (54), 153 (28), 143 (15), 142 (43), 141 (41), 140 (95), 128 (18), 127 (44), 116 (20), 115 (21), 114 (21), 113 (27), 81 (22), 76 (10), 63 (20) 56 (24)

TLC: R_f 0.31 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

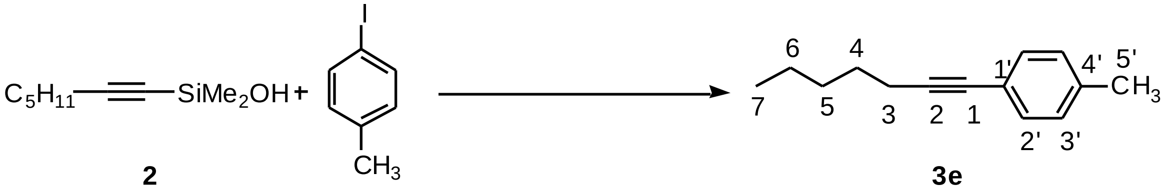
GC: t_R 12.40 min (HP-5, 15 psi, 175 ^{0}C for 7 min, 25 ^{0}C/min to 225 ^{0}C)

Analysis: $C_{14}H_{15}N$ (197.28)

Calcd: C, 85.24; H, 7.66 N, 7.10%

Found: C, 85.12; H, 7.72 N, 7.18%

Preparation of 1-(1-Heptynyl)-4-methylbenzene (3e) (Table 2, entry 5)



Following General Procedure II, 4-iodotoluene (218 mg, 1.00 mmol) was combined with potassium trimethylsilanolate (256 mg, 2.00 mmol, 2.0 equiv), copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187 mg, 1.1 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The product **3e** was obtained as a colorless oil in 91% yield (169 mg).

Data for 1-(1-Heptynyl)-4-methylbenzene **(3e)**:

bp: 150 ^{0}C (0.5 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

7.29 (d, *J* = 8.0, 2 H, 2 x HC(2')), 7.08 (d, *J* = 7.5, 2 H, 2 x HC(3')), 2.39 (t, *J* =7.0, 2 H, $H_2C(3)$), 2.33 (s, 3 H, $H_3C(5')$), 1.61 (pent, *J* = 7.5, 2 H, $H_2C(4)$), 1.34-1.46 (m, 4 H, H_2C(5 and 6), 0.93 (t, *J* = 7.5, 3 H, $H_3C(7)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

137.1 (C(4')), 131.1 (C(2')), 128.7 (C(3')), 120.7 (C(1')), 89.4 (C(1)), 80.3 (C(2)), 30.8 (C(5)), 28.2 (C(4)), 21.9 (C(6)), 21.1 C(5')), 19.1 (C(3)), 13.7 (C(7))

IR: (neat)

2957 (s), 2932 (s), 2860 (s), 2200 (w), 1701 (w), 1509 (s), 1466 (s), 1106 (w)

MS: (EI, 70 ev)

186 (M^+, 63), 171 (12), 158 (12), 157 (54), 145 (12), 144 (18), 143 (41), 142 (29), 141 (15), 131 (66), 130 (15), 129 (100), 128 (42), 127 (16), 116 (16), 115 (30), 105 (16), 91 (15), 77 (12)

TLC: R_f 0.55 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

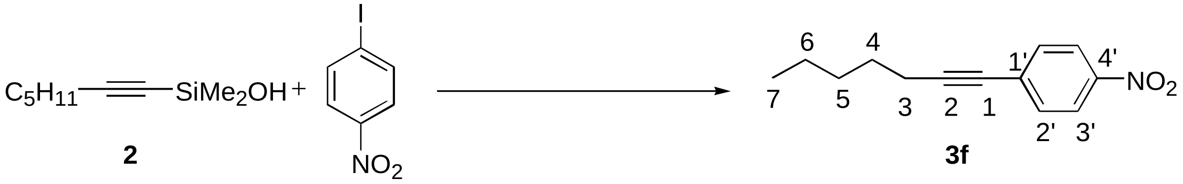
GC: t_R 10.00 min (HP-5, 15 psi, 125 ^{0}C for 4 min, 50 ^{0}C/min to 250 ^{0}C)

Analysis: $C_{14}H_{18}$ (186.29)

Calcd: C, 90.26; H, 9.74%

Found: C, 90.33; H, 9.82%

Preparation of 1-(1-Heptynyl)-4-nitrobenzene (3f) (Table 2, entry 6)



Following General Procedure II, 4-iodonitrobenzene (498 mg, 2.00 mmol) was combined with potassium trimethylsilanolate (512 mg, 4.00 mmol, 2.0 equiv), copper(I) iodide (19 mg, 0.10 mmol, 0.05 equiv), 4 mL of DME, dimethyl(1-heptynyl)silanol (375 mg, 2.2 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (35 mg, 0.05 mmol, 0.025 equiv). The product **3f** was obtained as a bright yellow oil in 75% yield (328 mg).

Data for 1-(1-Heptynyl)-4-nitrobenzene **(3f)**:

bp: 155 ^{0}C (0.1 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

8.15 (dd, *J* = 2.5, 8.5, 2 H, 2 x HC(3’)), 7.50 (dd, *J* = 2.5, 7.5, 2 H, 2 x HC(2’)), 2.42 (t, *J* =7.0, 2 H, H_2C(3)), 1.61 (pent, *J* = 7.0, 2 H, H_2C(4)), 1.34-1.45 (m, 4 H, H_2C(5 and 6), 0.93 (t, *J* = 7.0, 3 H, H_3C(7))

^{13}C NMR: (126 MHz, $CHCl_3$)

146.6 (C(4’)), 132.3 (C(2’)), 131.2 (C(1’)), 123.5 (C(3’)), 96.8 (C(1)), 79.3 (C(2)), 31.1 (C(5)), 28.1 (C(4)), 22.2 (C(6)), 19.5 (C(3)), 13.9 (C(7))

IR: (neat)

2932 (m), 2860 (m), 2360 (w), 2219(w), 1604 (s), 1594 (s), 1518 (s), 1342(s), 1107 (m), 853 (s), 750 (m)

MS: (EI, 70 ev)

217 (M$^+$, 55), 202 (30), 189 (18), 188 (100), 175 (12), 171 (12), 161 (12), 160 (16), 158 (28), 156 (18), 147 (18), 145 (11), 144 (14), 143 (19), 142 (78), 141 (40), 131 (18), 130 (28), 129 (49), 128 (80), 127 (24), 117 (19), 116 (64), 115 (65), 114 (45), 113 (23), 103 (12), 102 (36), 101 (14), 91 (17), 89 (19), 88 (22), 87 (12), 81 (38), 77 (20), 76 (13), 75 (19), 74 (10), 68 (17), 65 (10), 63 (30), 62 (13), 57 (14), 55 (41)

TLC: R_f 0.42 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

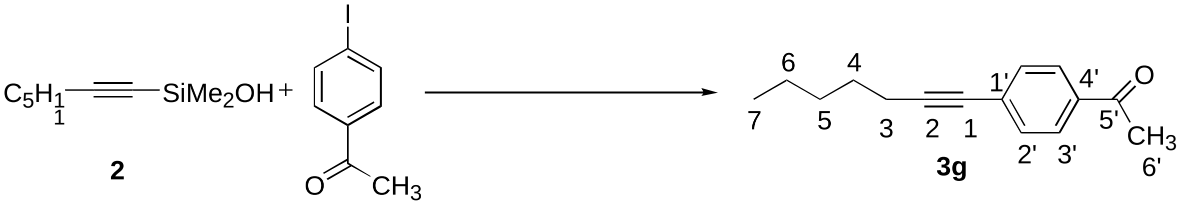
GC: t_R 10.88 min (HP-5, 15 psi, 125 ^{0}C for 4 min, 50 ^{0}C/min to 250 ^{0}C)

Analysis: $C_{13}H_{15}NO_2$ (217.26)

Calcd: C, 71.87; H, 6.96 N, 6.45%

Found: C, 71.65; H, 6.89 N, 6.48%

Preparation of 1-[4-(1-Heptynyl)phenyl]ethanone (3g) (Table 2, entry 7)



Following General Procedure II, 4-iodoacetophenone (246 mg, 1.00 mmol) was combined with potassium trimethylsilanolate (256 mg, 2.00 mmol, 2.0 equiv), copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187 mg, 1.1 mmol, 1.1 equiv), and PdCl$_2$(PPh$_3$)$_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The product **3g** was obtained as a colorless oil in 87% yield (187 mg).

Data for 1-[4-(1-Heptynyl)phenyl]ethanone **(3g)**:

bp: 155 ^{0}C (1.0 mmHg, ABT)

^{1}H NMR: (500 MHz, CHCl$_3$)

7.87 (d, *J* = 8.0, 2 H, 2 x HC(3’)), 7.46 (d, *J* = 7.5, 2 H, 2 x HC(2’)), 2.58 (s, 3 H, H$_3$C(6')), 2.42 (t, *J* =7.0, 2 H, H$_2$C(3)), 1.61 (pent, *J* = 7.5, 2 H, H$_2$C(4)), 1.34-1.45 (m, 4 H, H$_2$C(5 and 6), 0.92 (t, *J* = 7.0, 3 H, H$_3$C(7))

^{13}C NMR: (126 MHz, CHCl$_3$)

197.2 (C(5')), 135.4 (C(4’)), 131.4 (C(2’)), 128.9 (C(1’)), 127.9 (C(3’)), 94.2 (C(1)), 79.8 (C(2)), 30.8 (C(5)), 28.0 (C(4)), 26.3 (C(6')), 21.9 (C(6)), 19.2 (C(3)), 13.7 (C(7))

IR: (neat)

3353 (m), 2933 (s), 2861 (s), 2360 (w), 2218 (m), 1927 (w), 1684 (s), 1601 (s), 1403(s), 1357 (s), 1263 (s), 1178 (m), 956 (s), 840 (s)

MS: (EI, 70 ev)

214 (M^+, 47), 200 (17), 199 (100), 185 (30), 171 (15), 157 (36), 155 (11), 143 (33), 142 (31), 141 (13), 129 (61), 128 (32), 127 (20), 115 (39), 114 (46), 113 (17), 101 (11), 88 (14), 77 (12), 75 (11), 63 (17)

TLC: R_f 0.16 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

GC: t_R 10.51 min (HP-5, 15 psi, 125 ^{0}C for 4 min, 50 ^{0}C/min to 250 ^{0}C

Analysis: $C_{15}H_{18}O$ (214.30)

Calcd: C, 84.07; H, 8.47%

Found: C, 84.21; H, 8.57%

Preparation of 3-(1-Heptynyl)benzenemethanol (3h) (Table 2, entry 8)

2 **3h**

Following General Procedure II, 3-iodobenzyl alcohol (234 mg, 1.00 mmol) was combined with potassium trimethylsilanolate (256 mg, 2.00 mmol, 2.0 equiv), copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187 mg, 1.1 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The product **3h** was obtained as a colorless oil in 84% yield (169 mg).

Data for 3-(1-Heptynyl)benzenemethanol **(3h)**:

bp: 140 ^{0}C (0.5 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

7.36 (s, 1 H, HC(2’)), 7.30 (td, *J* = 1.5, 7.0 1 H, HC(6’)), 7.20-7.24 (m, 2 H, HC(5’), HC(4’)), 4.59 (d, *J* =4.0, 2 H, H_2C(7')), 2.38 (t, *J* =7.0, 2 H, H_2C(3)), 2.22 (d, *J* =4.0, 1 H, -OH), 1.62 (pent, *J* = 7.0, 2 H, H_2C(4)), 1.32-1.44 (m, 4 H, H_2C(5 and 6), 0.90 (t, *J* = 7.5, 3 H, H_3C(7))

^{13}C NMR: (126 MHz, $CHCl_3$)

140.8 (C(1’)), 130.7 (C(6’)), 129.9 (C(2’)), 128.4 (C(5’)), 126.0 (C(4’)), 124.2 (C(3’)), 90.6 (C(1)), 80.3 (C(2)), 64.7 C(7')), 31.0 (C(5)), 28.3 (C(4)), 22.2 (C(6)), 19.3 (C(3)), 13.9 (C(7))

IR: (neat)

3601 (m), 3448 (w,b), 2959 (s), 2861 (s), 2365 (w), 2228 (w), 1602 (m), 1483 (m), 1459 (m), 1431 (m), 1379 (m), 1269 (s), 1033 (m), 793 (s), 728 (s)

MS: (EI, 70 ev)

202 (M^+, 62), 173 (32), 171 (13), 155 (18), 145 (61), 144 (11), 143 (62), 142 (16), 141 (15), 131 (16), 130 (13), 129 (88), 128 (52), 127 (17), 118 (11), 117 (100), 116 (17), 115(65), 91 (32), 77 (15), 63 (12)

TLC: R_f 0.05 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

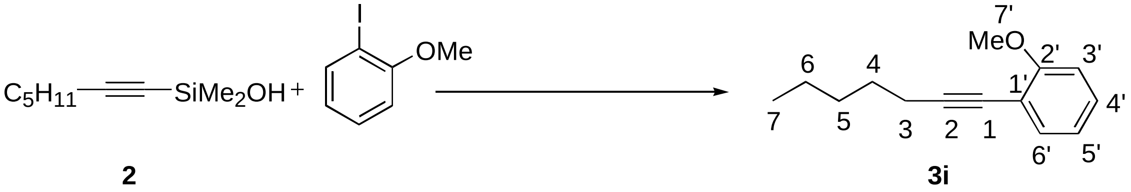
GC: t_R 9.94 min (HP-5, 15 psi, 125 ^{0}C for 4 min, 50 ^{0}C/min to 250 ^{0}C)

Analysis: $C_{14}H_{18}O$ (202.29)

Calcd: C, 83.12; H, 8.97%

Found: C, 83.08; H, 9.27%

Preparation of 1-(1-Heptynyl)-2-methoxybenzene (3i) (Table 2, entry 9)[1]



Following General Procedure II, 2-iodoanisole (234 mg, 1.00 mmol) was combined with potassium trimethylsilanolate (256 mg, 2.00 mmol, 2.0 equiv), copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187 mg, 1.1 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The product **3i** was obtained as a colorless oil in 93% yield (188 mg).

Data for 1-(1-Heptynyl)-2-methoxybenzene (**3i**):

bp: 115 ^{0}C (0.5 mmHg, ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

7.38 (dd, *J* = 2.0, 7.5, 1 H, HC(5')), 7.23 (td, *J* = 2.0, 7.5 1 H, HC(4')), 6.84-6.89 (m, 2 H, HC(3'), HC(6')), 3.88 (s, 3 H, $H_3C(7')$), 2.46 (t, *J* =7.0, 2 H, $H_2C(3)$), 1.62 (pent, *J* = 7.5, 2 H, $H_2C(4)$), 1.43 (pent, *J* = 7.5, 2 H, $H_2C(5)$), 1.37 (pent, *J* = 7.0, 2 H, $H_2C(6)$), 0.92 (t, *J* = 7.0, 3 H, $H_3C(7)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

159.6 (C(6')), 133.4 (C(2')), 128.6 (C(4')), 120.1 (C(5')), 112.9 (C(1')), 110.3 (C(3')), 94.5 (C(1)), 76.3 (C(2)), 55.5 (C(7')) 30.9 (C(5)), 28.3 (C(4)), 22.0 (C(6)), 19.5 (C(3)), 13.7 (C(7))

IR: (neat)

2932 (m), 2859 (m), 1595 (m), 1575 (m), 1492 (s), 1464 (m), 1433 (m), 1261 (s), 1117 (m), 1026 (m), 750 (s)

MS: (EI, 70 ev)

202 (M^+, 97), 187 (14), 173 (45), 160 (16), 159 (38), 158 (23), 148 (13), 147 (100), 145 (35), 144 (19), 134 (12), 132 (16), 131 (58), 129 (22), 128 (2), 127 (16), 121 (23), 119 (11), 117 (26), 116 (20), 115 (78), 107 (15), 103 (10), 102 (20), 91 (61) 89 (19), 77 (19), 76 (12), 75 (12), 65 (11), 63 (16)

TLC: R_f 0.31 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

GC: t_R 9.47 min (HP-5, 15 psi, 125 ^{0}C for 4 min, 50 ^{0}C/min to 250 ^{0}C)

Analysis: $C_{14}H_{18}O$ (202.29)

Calcd: C, 83.12; H, 8.97%

Found: C, 83.19; H, 8.93%

Preparation of 1-(1-Heptynyl)-2-methylbenzene (3j) (Table 2, entry 10)

Following General Procedure II, 2-iodotoluene (218 mg, 1.00 mmol) was combined with potassium trimethylsilanolate (256 mg, 2.00 mmol, 2.0 equiv), copper(I) iodide (9.6 mg, 0.05 mmol, 0.05 equiv), 2 mL of DME, dimethyl(1-heptynyl)silanol (187 mg, 1.1 mmol, 1.1 equiv), and $PdCl_2(PPh_3)_2$ (17.2 mg, 0.025 mmol, 0.025 equiv). The product **3j** was obtained as a colorless oil in 92% yield (171 mg).

Data for 1-(1-Heptynyl)-2-methylbenzene **(3j):**

bp: 115 ^{0}C (0.5 mm Hg ABT)

^{1}H NMR: (500 MHz, $CHCl_3$)

7.36 (d, *J* = 7.5, 1 H, HC(6’)), 7.17-7.18 (m, 2 H, HC(3’), HC(5’)), 7.10-7.13 (m, 1 H, HC(4’)), 2.46 (t, *J* =7.0, 2 H, $H_2C(3)$), 2.43 (s, 3 H, $-CH_3$), 1.62 (pent, *J* = 7.5, 2 H, $H_2C(4)$), 1.44 (pent, *J* = 6.5, 2 H, $H_2C(5)$), 1.38 (pent, *J* = 6.5, 2 H, $H_2C(6)$), 0.92 (t, *J* = 7.5, 3 H, $H_3C(7)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

139.7 (C(6’)), 131.5 (C(2’)), 129.0 (C(5’)), 127.2 (C(4’)), 125.1 (C(3’)), 123.6 (C(1’)), 94.2 (C(1)), 79.1 (C(2)), 30.8 (C(5)), 28.3 (C(4)), 22.0 (C(6)), 20.4 ($-CH_3$), 19.2(C(3)), 13.7 (C(7))

IR: (neat)

2957 (s), 2932 (s), 2860 (s), 2234 (w), 1912 (w), 1600 (s), 1486 (s), 1456 (s), 1378 (m), 1330 (m), 1044 (m), 755 (s)

MS: (EI, 70 ev)

186 (M^+, 96), 171 (11), 158 (11), 157 (62), 144 (13), 143 (34), 142 (27), 141 (18), 132 (10), 131 (88), 130 (15), 129 (100), 128 (93), 127 (28), 116 (15), 115 (39), 105 (18), 91 (15)

TLC: R_f 0.55 (hexane/EtOAc, 19/1) [silica gel, $KMnO_4$]

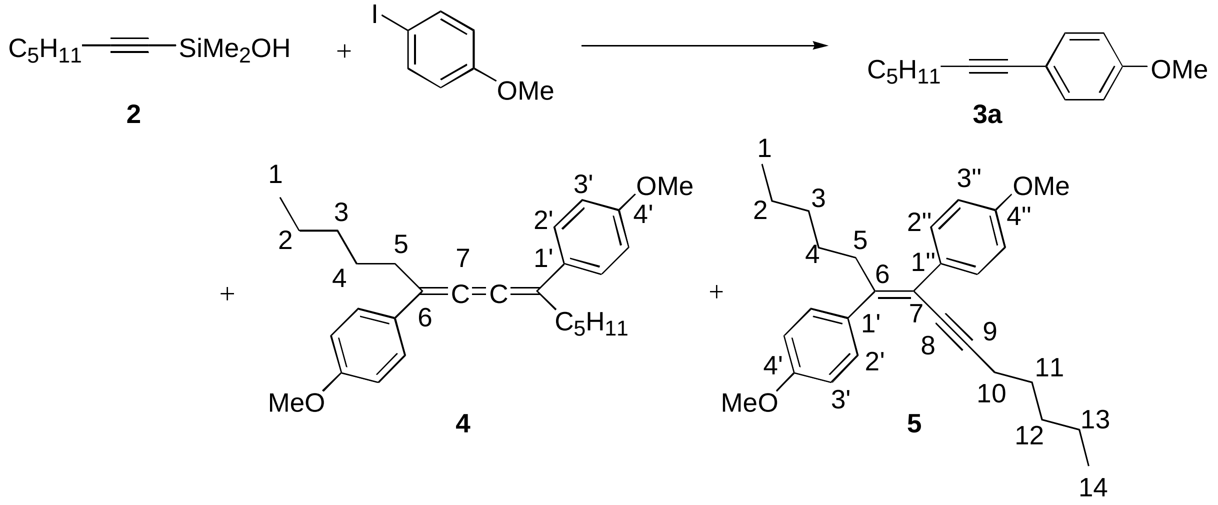
GC: t_R 8.67 min (HP-5, 15 psi, 125 ^{0}C for 4 min, 50 ^{0}C/min to 250 ^{0}C)

Analysis: $C_{14}H_{18}$ (186.29)

Calcd: C, 90.26; H, 9.74%

Found: C, 89.97; H, 9.82%

Preparation of 1-(1-Heptynyl)-4-methoxybenzene (3a) with Isolation of 1,1'-(1,4-Dipentyl-1,2,3-butatriene-1,4-diyl)bis[4-methoxybenzene] (4) and 1,1'-[1-Pentyl-2-(1-heptynyl)-1,2-ethenediyl]bis[4-methoxybenzene] (5)



To an oven-dried, 25-mL, round-bottom flask equipped with a magnetic stir bar was added 512 mg (4.0 mmol, 4.0 equiv) of potassium trimethylsilanolate under a dry nitrogen atmosphere. To this was added sequentially 4 mL of DME, dimethyl(1-heptynyl)silanol (375 mg, 2.2 mmol, 1.1 equiv), 4-iodoanisole (468 mg, 2.0 mmol), and $PdCl_2(PPh_3)_2$ (34.4 mg, 0.05 mmol, 0.025 equiv). The resulting solution was stirred at room temperature for 8 h. The reaction mixture was taken up in 15 mL of Et_2O. The combined organic phases were washed with water (2 x 15 mL) and the aqueous phase was back extracted with Et_2O (2 x 15 mL). The combined organic extracts were washed with brine (15 mL) and the were dried over $MgSO_4$. The volatile solvents were removed in vacuo to provide a dark oil. The oil was taken up in 5 mL of Et_2O and loaded onto a 30 mm x 40 cm silica gel column which was eluted with pentane/Et_2O), 50/1, (5 psi) to afford **3a** (109 mg, 59%) as a pale yellow along with a yellow semisolid. The semisolid was recrystallized from 3 mL of hot ethanol to give 29 mg (7%) of **4** as a bright-yellow, crystalline solid. The mother liquor was concentrated in vacuo to remove the volatile solvents. The resulting oil was purified by preparative TLC with pentane/Et_2O, 20/1 to give 15 mg (4%) of **5** as a colorless oil.

Data for **4**:

^{1}H NMR: (500 MHz, $CHCl_3$)

7.57 (dd, *J* = 2.5, 8.5, 4 H, 4 x HC(2')), 6.88(dd, *J* = 2.5, 8.5, 4H, 4 x HC(1')), 3.83 (s, 6 H, 2 x -OCH_3), 2.67 (t, *J* =9.5, 4 H, 2 x $H_2C(5)$), 1.79 (pent, *J* = 9.5, 4 H, 2 x $H_2C(4)$), 1.40-1.54 (m, 8 H, 4 x H_2C (2, 3)), 0.93 (t, *J* = 9, 6 H, 2 x $H_3C(1)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

158.84 (C(4')), 151.35 (C(7)), 132.00 (C(2')), 127.42 (C(1')), 117.47 (C(3')), 113.79 (C(6)), 55.32 (-OMe), 33.27 (C(5)), 31.73 (C(4)), 28.56 (C(3)), 22.67 (C(2)), 14.03, (C(1))

MS: (EI, 70 eV)

404 (M^+, 100), 347 (22), 277 (13), 121 (22)

Data for **5**:

^{1}H NMR: (500 MHz, $CHCl_3$)

7.43 (d, *J* = 8.5, 2 H, 2 x HC(3'')), 7.30 (d, *J* = 9, 2 H, 2 x HC(3')), 6.89 (m, 4 H 2 x (HC(2', 2'')), 3.83 (s, 6 H, 2 x -OMe), 2.40 (t, *J* = 7.5, 2 H, $H_2C(10)$), 2.14 (t, *J* = 7, 2 H, $H_2C(5)$), 1.11-1.34 (m, 12 H, H_2C(2,3,4,11,12,13), 0.83 (t, *J* = 7, 3 H, $H_3C(14)$), 0.77 (t, *J* = 7, 3 H, $H_3C(1)$)

^{13}C NMR: (126 MHz, $CHCl_3$)

158.49 (C(4')), 158.41 (C(4'')), 147.69 (C(6)), 134.27 (C(1')), 133.16 (C(1'')), 129.92 (C(2')), 129.79 (C(2'')), 119.91 (C(7)), 113.47 (C(3')), 112.99 (C(3'')), 92.53 (C(9)), 82.48 (C(8)), 55.23 (OMe), 55.12 (OMe), 33.81 (C(10)), 31.60 (C(5)), 30.86(C(11)), 28.36 (C(4)), 28.22 (C(12)), 22.26 (C(3)), 22.19 (C(13)), 19.56(C(2)), 13.93 (C(14)), 13.91 (C(1))

MS: (EI, 70 eV)

404 (M^+, 100), 347 (24), 277 (9)

References

(1) Chapdelain, M.; Warwick, P.; Shaw, A. *J. Org. Chem.* **1989**, *54*, 1218.

(2) Okuro, K.; Furuune, M.; Enna, M.; Miura, M.; Nomura, M. *J. Org. Chem.* **1993**, *58*, 4716.